AF Technical Report No. 6465 March 1951

RECOGNITION TIME FOR DIAL-TYPE NUMERALS AS A FUNCTION OF SIZE AND BRIGHTNESS

Mason N. Crook
Frances Schulze Baxter

The Institute for Applied Experimental Psychology
Tufts College

Aero Medical Laboratory
Contract No. W33-038 ac-14559
E. O. No. R694-15

United States Air Force
Wright Air Development Center
Wright-Patterson Air Force Base, Dayton, Ohio

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The information furnished herewith is made available for study upon the understanding that the Government's proprietary interests in and relating thereto shall not be impaired. It is desired that the Office of the Judge Advocate, Air Materiel Command, Wright-Patterson AFB, Dayton, Ohio, be promptly notified of any apparent conflict between the Government's proprietary interests and those of others.

The U. S. Government is absolved from any litigation which may ensue from the contractor's infringing on the foreign patent rights which may be involved.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1951

3. REPORT TYPE AND DATES COVERED
FINAL 1 MAR 51 - 31 MAR 51

4. TITLE AND SUBTITLE
RECOGNITION TIME FOR DIAL-TYPE NUMERALS AS A FUNCTION OF SIZE AND BRIGHTNESS

5. FUNDING NUMBERS
C W33-038 ac-14559
E.O. No. R694-15

6. AUTHOR(S)
MASON N. CROOK
FRANCES SCHULZE BAXTER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
THE INSTITUTE FOR APPLIED EXPERIMENTAL PSYCHOLOGY
TUFTS COLLEGE

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AERO MEDICAL LABORATORY
WRIGHT AIR DEVELOPMENT CENTER
WRIGHT-PATTERSON AFB, OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AF-TR-6465

11. SUPPLEMENTARY NOTES
ATI#119 387

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Recognition time as a function of digit size and brightness was determined for white dial type digits on a dark ground. The brightness range was from 0.003 to 0.1 foot-lambert. Average recognition time under the most favorable conditions tried was about 0.6 second. As size or brightness decreased, recognition time increased, at first slowly and then more rapidly. The effect of such secondary factors as individual differences, grouping of digits, and reduction in brightness contrast was relatively small when size-brightness conditions were favorable, but tended to be much larger when size-brightness conditions became difficult. So far as the variables here investigated are concerned, it would be desirable to maintain operational conditions such that single digits would be recognized by the median subject within about 0.7 second. The necessary size-brightness combinations, however, would involve complications with space limitations and dark adaptation, so practical compromises are necessary.

14. SUBJECT TERMS

15. NUMBER OF PAGES
30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
U	U	U	SAR

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	Contract	**PR**	Project
G	Grant	**TA**	Task
PE	Program Element	**WU**	Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

- **DOD** - See DoDD 5230.24, "Distribution Statements on Technical Documents."
- **DOE** - See authorities.
- **NASA** - See Handbook NHB 2200.2.
- **NTIS** - Leave blank.

Block 12b. Distribution Code.

- **DOD** - Leave blank.
- **DOE** - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
- **NASA** - Leave blank.
- **NTIS** - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

FOREWORD

This report was prepared by the Institute for Applied Expermental Psychology, Tufts College, under USAF Contract No. W33-038 ac-14559. The contract is administered by the Aero Medical Laboratory, Research Division, Wright Air Development Center, under Expenditure Order No. R694-15 (PO-12), with Dr. Walter F. Grether acting as project engineer.

ABSTRACT

Recognition time as a function of digit size and brightness was determined for white dial type digits on a dark ground. The brightness range was from 0.003 to 0.1 foot-lambert. Average recognition time under the most favorable conditions tried was about 0.6 second. As size or brightness decreased, recognition time increased, at first slowly and then more rapidly. The effect of such secondary factors as individual differences, grouping of digits, and reduction in brightness contrast was relatively small when size-brightness conditions were favorable, but tended to be much larger when size-brightness conditions became difficult. So far as the variables here investigated are concerned, it would be desirable to maintain operational conditions such that single digits would be recognized by the median subject within about 0.7 second. The necessary size-brightness combinations, however, would involve complications with space limitations and dark adaptation, so practical compromises are necessary.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

Robert H Blount

ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Research Division

CONTENTS

RECOGNITION TIME FOR DIAL-TYPE NUMERALS AS A FUNCTION OF SIZE AND BRIGHTNESS

SECTION I

INTRODUCTION

This report presents data on the time required to recognize numerals of various sizes at various low brightness levels. The standard Army-Navy Aeronautical numerals shown in Figure 4 were used. The height/stroke-width ratio was 8/1. When numeral size was changed the design remained constant.

The effect of varying stroke-width, configuration, and other aspects of numeral design was investigated in a parallel series of studies which will be covered in subsequent reports.

Of previous work on the size and brightness variables, the most relevant was a war-time study by Craik (1). Craik determined the reading time as a function of brightness for white dial type numerals on a dark ground under faint flood lighting. The total brightness range covered was from about 0.0001 to 0.01 ft-L (foot-lambert). Four numeral sizes, subtending visual angles in the vertical dimension of 15', 36', 1° 12', and 2° 24', were used for different parts of the brightness range. Data were reported from two subjects. It was found that, for each numeral size, reading time increased progressively as brightness decreased. For a constant reading time of 1.5 sec., the digit area varied approximately inversely with brightness.

The present study was similar to Craik's in general plan, but differed in various details of instrumentation and procedure, and provided considerably more data.

The brightness range was from 0.003 to 0.1 ft-L. In the main experiment, digits were presented singly at maximum brightness contrast. Grouping of digits and reduced contrast were introduced later.

In operational situations various systems of night cockpit lighting have been tried, sometimes separately and sometimes in combination. Among them are floodlighting, edge lighting of dials, phosphorescence of markings, fluorescence of markings, and transillumination of markings. These systems are likely to differ in uniformity of illumination within a given area, wave-length composition, brightness of markings, and brightness of background. Such differences, rather than differences among reflection, radiation, and transmission per se, are the important ones for visual discrimination and dark adaptation.

The importance of uniform illumination over, for example, a dial face, hardly needs comment. The superiority of the long wave end of the spectrum for minimizing interference with dark adaptation is well known. Brightness of markings is a factor in discrimination and also in level of adaptation. Brightness of background is a factor in adaptation, is one term in the contrast

between background and markings, and contributes to the visual frame of reference which determines ease of accommodation and orientation.

The present experiments were concerned with visual discrimination as a function of the two illumination variables, brightness of markings and contrast between markings and background, and the two non-illumination variables, digit size and grouping.

An incandescent light source was used. The digits, background, and reference guides were projected from behind onto an opal flash glass viewing screen, and the field was therefore transilluminated. Brightnesses of figure and ground were separately controllable, and so far as these variables alone are concerned, the visual situation was presumably comparable to that of a floodlit surface of the same specifications.

The sections on apparatus and general procedure apply to all four of the experiments reported. Conditions and results of the experiments will be separately described, and a general discussion section will follow.

SECTION II

EXPERIMENTATION

A. Apparatus and General Procedure

1. The Projector

The digits were presented by means of a special projector which permitted the size of the image to be continuously varied without loss of focus. The projection screen was a piece of opal flash glass 12 in. square. The front surface of the screen was viewed by the subjects at a distance of 28 in. The optical system for projecting the digits, positioned behind the screen, had two moving elements, the lens and the slide holder. The light source was attached to the slide holder and moved with it. Settings were controlled by means of a crank which, through a rack and pinion, advanced the lens and also rotated a cam. The cam varied the position of the slide holder in such a way as to keep the image in focus. A camera lens of 5.5 in. focal length was used. The total lens excursion was about 8 in. and that of the slide holder a little less than 3 in. Image height could be varied over a range of four to one, from one-half to twice the size of the original. Overall length of the device, including the projection screen, was about 38 in.

The light for digit images was a 100-watt projection bulb operating on 115 volts AC through a voltage stabilizer.

It was necessary to eliminate from the system a variation in image brightness which occurred as a function of size. For this purpose an iris diaphragm, mounted at the lens, was so geared to the drive mechanism that variation in the iris area provided an automatic compensatory light control and brightness was made independent of the image size settings.

To permit adjustment of image brightness to the level desired, crossed polaroids and holders for Wratten neutral tint filters were positioned between the lens and the slide holder.

This part of the light system was calibrated with a Macbeth illuminometer. Mean readings of a series were reproducible within plus or minus 2%.

Background illumination was provided by four flashlight bulbs at the corners of an 8 1/2 in. square located 7 in. behind the projection screen. These bulbs were operated at low voltage, and by suitable arrangements of filters and diaphragms either all or part of the screen could be flooded by light of controlled brightness. In the main experimental routine the immediate background of the digit images was kept dark so brightness contrast was maximal. But with only a digit image and no frame of reference in the visual field, disturbing autokinetic movements tended to occur. Therefore, on the lateral edges of the screen vertical strips about 1 1/2 in. wide by 12 in. high were very faintly illuminated. This left a 9 by 12 in. central region of the screen dark. The strips, which the subject could see only after some dark adaptation, were effective in minimizing the autokinetic effect.

This part of the light system was checked with a Taylor low brightness meter. Brightness of the strips was estimated to be about 5×10^{-6} ft-L, but was too near the lower limit of the meter for accurate measurement.

A series of hoods effectively shielded the subject's eyes and the optical system from the experimenter's working light.

This projector could be used in two ways: (1) to obtain size thresholds by starting an image below the threshold of recognition and increasing the size until it was correctly reported, and (2) as a convenient means of getting a series of fixed image sizes. The first of these procedures was used in some of the design studies to be reported later. In the work here reported, only fixed image sizes were used.

Slides for projection were prepared as follows. A cut-out of the digit about 1 9/16 in. high was made in black cardboard and pasted on glass. This original was reduced in two steps, both reductions being transparencies on Kodalith Ortho Type 2 film. The second reduction, providing a transparent image about 3/16 in. high on a dark ground, was mounted over a hole in the center of a square of black cardboard cut to fit the slide holder in the projector. Dimensions of cardboard cut-outs were systematically checked, photographic processes were well standardized, and dimensions of second reductions were spot checked.

2. The Control and Response Circuits

The digits were exposed by an electrically controlled shutter. Response was registered by a throat microphone operating through an amplifier and relay system. Recording was on a strip of polygraph paper which was advanced by a constant speed motor at the rate of 13.2 mm. per sec. When the experimenter pressed a finger key the shutter was opened, a mark was made on the polygraph paper, and a switch was closed in the amplifier output circuit. A calibration test showed the shutter and polygraph record to be synchronized within 0.02 sec. When the subject responded the shutter was closed, a second mark was made on the polygraph paper, and the switch in the output circuit was opened. The switch in the output circuit had the effect of making the microphone inoperative except in the short interval between exposure and response. The length of this interval was taken as the recognition time, and could be read in millimeters from the polygraph paper.

In designing these circuits it was necessary to adapt them in a number of respects to features of the equipment already in use. Because of such specialized details they would be of only limited interest and are therefore not described in full. A description of a somewhat comparable circuit for a throat microphone has been published by Roush and Hamburger (5).

3. General Procedure

The procedure was designed to determine the average time in which the digits could be correctly identified.

The subject was instructed to name the exposed digit as soon as he could be sure of naming it correctly. On being given a ready signal the subject watched the center of the screen. A digit or group of digits was then exposed and remained until the subject responded. If the response was incorrect, the item was repeated a little later in the series. The experimenter marked the order of the items on the polygraph record.

B. Detailed Procedure and Results

1. Experiment 1: Recognition Time for Digits Presented Singly

a. Conditions

This experiment was planned to provide the main body of data. Digits were presented singly, against a dark ground, with the faintly luminous lateral strips to provide a frame of reference. Four brightness levels were selected at approximately equal logarithmic intervals, 0.003, 0.01, 0.03, and 0.1 ft-L. At each brightness level a number of digit sizes were so chosen as to produce recognition times from the fastest obtainable to several seconds. Complications of experimental design made it advisable to limit the number of sizes per brightness level to three or four. Considerable preliminary experimentation was therefore done and three basic digit heights were settled on for each

brightness, as follows:1/ for 0.003 ft-L, 0.36, 0.63, and 0.90 in.; for 0.01 ft-L, 0.26, 0.36, and 0.46 in.; for 0.03 ft-L, 0.14, 0.22, and 0.36 in.; for 0.1 ft-L, 0.12, 0.18, and 0.24 in. These sizes were incorporated in the basic experimental design. As an aid in establishing the minimum response times, oversize digits were also presented, twice the height of the largest basic digits at each brightness except at 0.003 ft-L, where because of apparatus limitations they were 46% taller than the largest basic digits. To reduce experimental time the oversize digits were divided into two sets and each set given to half the subjects, immediately after the regular trials at each brightness level.

As a means of getting an estimate of simple response time in the experimental situation, at the end of the regular routine seven of the subjects were asked to respond immediately when they saw a light spot 1.26 in. in diameter, with no discrimination required. These trials were at the same brightnesses as the trials just completed.

Subjects were male college students with 20/20 vision on the Lebensohn Test at 14 in. Sixteen subjects were used for two periods each. All had had one period of previous experience in a somewhat related experimental situation.

A single period included either the two higher or the two lower brightnesses. At each brightness, the three basic sizes appeared in a predetermined order and then in reverse order. In the first appearance of each size five digits were presented, in the second appearance the remaining five. Sequences of digits, sizes, and brightnesses were rearranged among subjects and periods to balance out the effect of serial position.

Ten digits, three sizes, and two brightnesses made 60 trials in the regular design pattern, a trial being one presentation. The full schedule for a subject's first period was as follows: eight practice trials, 30 regular trials at the first brightness, 5 trials on the oversize digits at the same brightness, a short rest interval, 30 regular trials at the second brightness, and 5 trials on the oversize digits at the same brightness. In a second period the 8 practice trials were replaced by 4 warming-up trials, and for 7 subjects the period was ended with from 8 to 11 trials on the light spot.

If a digit was not recognized in 10 seconds, the trial was terminated and 10 seconds recorded as the score.

b. Results

In Table IA are shown, for the three basic sizes at each brightness

1/ Following the usual convention for dial numerals, digit heights are given in inches. For rough estimates of visual angle equivalence, it can be noted that at our experimental viewing distance of 28 in., a digit 0.12 in. high subtends 14' 45", a 0.24 in. digit subtends just under 30', and a 0.48 in. digit just under 1°. Other conversions can be made from the abscissa scales of Figure 1.

the mean recognition times by individual digits, and for all digits combined; for the oversize digits at each brightness, means of all digits combined; and for the simple light spot, a mean for seven subjects. For two of the seven subjects, the light spot was at 0.003 ft-L, for three, at 0.01 ft-L, and for two, at 0.03 ft-L.

At a given basic size and brightness, mean recognition times for individual digits are based on 16 determinations (1 per subject), and for all digits combined, on 160 determinations. Means for all oversize digits combined at a given brightness are based on 80 determinations (16 subjects, 5 digits each). Mean response time to the light spot is based on 42 determinations (7 subjects, 6 trials each). The first few trials with the light spot sometimes produced erratic results, so trials were counted only after performance appeared to have settled down.

Means which include one or more of the arbitrary 10-sec. scores resulting from terminating exposures at that interval are underlined in Table I A. With one minor exception, the smallestdigit size only at each brightness is involved. The largest number of arbitrary scores entering into a mean for the ten digits combined is 24 out of the total of 160 scores for the 0.36 in. digit height at 0.003 ft-L, and the largest number for a single digit is five out of the total of 16 scores for digit 6 under the same conditions.

The mean scores for individual digits in Table I A show that, for the largest digit size at each brightness, the range by individual digits does not exceed 1.25/1, but for the smallest digit size the range at three of the brightnesses exceeds 2/1. Even this ratio is not large compared to the effects of some other variables. It is of interest to us in the present connection because it reflects the fact that reducing digit size impairs recognition of the difficult digits more than of the easy ones.

The distributions of scores by subjects show certain characteristics which are important for the type of application we are concerned with. The spread of performance within a group tends to be large, and to increase progressively as conditions become more difficult. Furthermore, the scores of the poorer subjects are affected most by difficult conditions, so the distributions show increasing skewness with increasing difficulty. A convenient way to present these aspects of the data for a group of 16 subjects is by quartile points. In Table I B are given, for the various size-brightness combinations, the scores on ten digits combined which separate the group of subjects into quarters, together with the means repeated from Table I A. As short time represents better performance, scores decrease from the 25th to the 75th percentile.

In Figure 1 the median recognition times have been plotted as a function of digit height, and curves smoothed by inspection have been drawn through the points for each of the four brightnesses. The inter-quartile ranges are also shown by vertical lines through the plotted medians. The top end of the line in each case designates the 25th percentile point, the bottom end the 75th percentile. The difference between the brightness levels, and the accelerated increase in recognition time with decrease in digit size, show

TABLE I A

MEAN RECOGNITION TIMES FOR DIGITS
PRESENTED SINGLY (16 ORIGINAL SUBJECTS)

	RECOGNITION TIME (sec.)							
	BRIGHTNESS .1 ft-L				BRIGHTNESS .03 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
DIGIT	.12	.18	.24	.48	.14	.22	.30	.60
1	1.79	1.30	.70	—	2.71	.84	.74	—
2	1.21	.90	.76	—	1.94	.84	.69	—
3	1.78	.91	.76	—	2.61	.85	.74	—
4	1.63	.86	.75	—	2.64	.87	.77	—
5	1.74	.91	.64	—	2.44	.82	.72	—
6	1.89	1.03	.70	—	2.79	.87	.71	—
7	1.12	.91	.74	—	1.35	.77	.67	—
8	2.20	1.59	.80	—	3.04	.91	.73	—
9	1.59	.88	.70	—	1.70	.76	.67	—
0	2.41	1.12	.77	—	3.28	.95	.76	—
MEAN	1.74	1.04	.73	(.59)	2.45	.85	.72	(.59)

	BRIGHTNESS .01 ft-L				BRIGHTNESS .003 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
DIGIT	.26	.36	.46	.92	.36	.63	.90	1.31
1	2.24	.98	.72	—	2.96	.79	.68	—
2	1.95	.97	.72	—	3.05	.76	.74	—
3	2.36	1.09	.82	—	4.37	.89	.77	—
4	2.80	.94	.77	—	3.61	1.08	.72	—
5	2.50	.95	.74	—	4.11	.80	.72	—
6	2.40	1.06	.73	—	4.11	.76	.75	—
7	1.73	.91	.69	—	2.02	.70	.68	—
8	2.39	1.06	.72	—	3.93	1.22	.70	—
9	1.95	.87	.67	—	3.62	1.02	.77	—
0	2.55	1.18	.80	—	2.78	.86	.72	—
MEAN	2.29	1.00	.74	(.62)	3.46	.89	.72	(.67)

Mean response time to light spot for 7 subjects, (2 at .03 ft-L, 3 at .01 ft-L, and 2 at .003 ft-L), 5 trials per subject. .32 sec.

Underlined figures include time scores from 1 or more subjects arbitrarily limited to 10 sec. Figures in parentheses based on only 5 digits per subject.

TABLE I B

MEANS, MEDIANS, AND 25th AND 75th PERCENTILES OF THE DISTRIBUTIONS OF RECOGNITION TIMES FOR DIGITS PRESENTED SINGLY (16 ORIGINAL SUBJECTS)

	RECOGNITION TIME (sec.)							
	BRIGHTNESS .1 ft-L				BRIGHTNESS .03 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
	.12	.18	.24	.48	.14	.22	.30	.60
MEAN	1.74	1.04	.73	(.59)	2.45	.85	.72	(.59)
75th PERCENTILE	.86	.66	.56	(.51)	1.05	.64	.55	(.49)
MEDIAN	1.14	.86	.66	(.58)	1.49	.80	.72	(.53)
25th PERCENTILE	1.80	1.28	.81	(.62)	3.24	1.05	.87	(.66)
	BRIGHTNESS .01 ft-L				BRIGHTNESS .003 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
	.26	.36	.46	.92	.36	.63	.90	1.31
MEAN	2.29	1.00	.74	(.62)	3.46	.89	.72	(.67)
75th PERCENTILE	.93	.72	.58	(.52)	1.46	.61	.59	(.57)
MEDIAN	1.15	.84	.67	(.55)	2.20	.66	.62	(.61)
25th PERCENTILE	2.86	1.22	.79	(.65)	6.71	.86	.73	(.67)

Median response time to light spot, 7 subjects, brightness range .003 to .03 ft-L. .33 sec.

Underlined figures are based on distributions which include 1 or more scores arbitrarily limited to 10 sec.

Figures in parentheses are based on only 5 digits per subject.

TABLE I C

MEANS, MEDIANS, AND 25th AND 75th PERCENTILES OF THE DISTRIBUTIONS OF RECOGNITION TIMES FOR DIGITS PRESENTED SINGLY (16 SUBJECTS, INCLUDING 5 REPLACEMENTS)

	RECOGNITION TIME (sec.)							
	BRIGHTNESS .1 ft-L				BRIGHTNESS .03 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
	.12	.18	.24	.48	.14	.22	.30	.60
MEAN	1.16	.84	.71	(.61)	<u>1.96</u>	.80	.72	(.59)
75th PERCENTILE	.86	.66	.56	(.51)	1.06	.64	.56	(.50)
MEDIAN	1.10	.81	.65	(.59)	<u>1.52</u>	.78	.68	(.55)
25th PERCENTILE	1.41	.90	.78	(.66)	<u>2.39</u>	.91	.80	(.64)
	BRIGHTNESS .01 ft-L				BRIGHTNESS .003 ft-L			
	DIGIT HEIGHT (in.)				DIGIT HEIGHT (in.)			
	.26	.36	.46	.92	.36	.63	.90	1.31
MEAN	1.26	.85	.69	(.62)	<u>2.74</u>	.88	.73	(.68)
75th PERCENTILE	.95	.70	.58	(.52)	1.65	.62	.60	(.57)
MEDIAN	1.05	.75	.63	(.56)	<u>2.14</u>	.71	.64	(.61)
25th PERCENTILE	1.36	.90	.71	(.62)	<u>2.64</u>	.87	.75	(.65)

Underlined figures are based on distributions which include one or more scores arbitrarily limited to 10 sec.

Figures in parentheses are based on only 5 digits per subject.

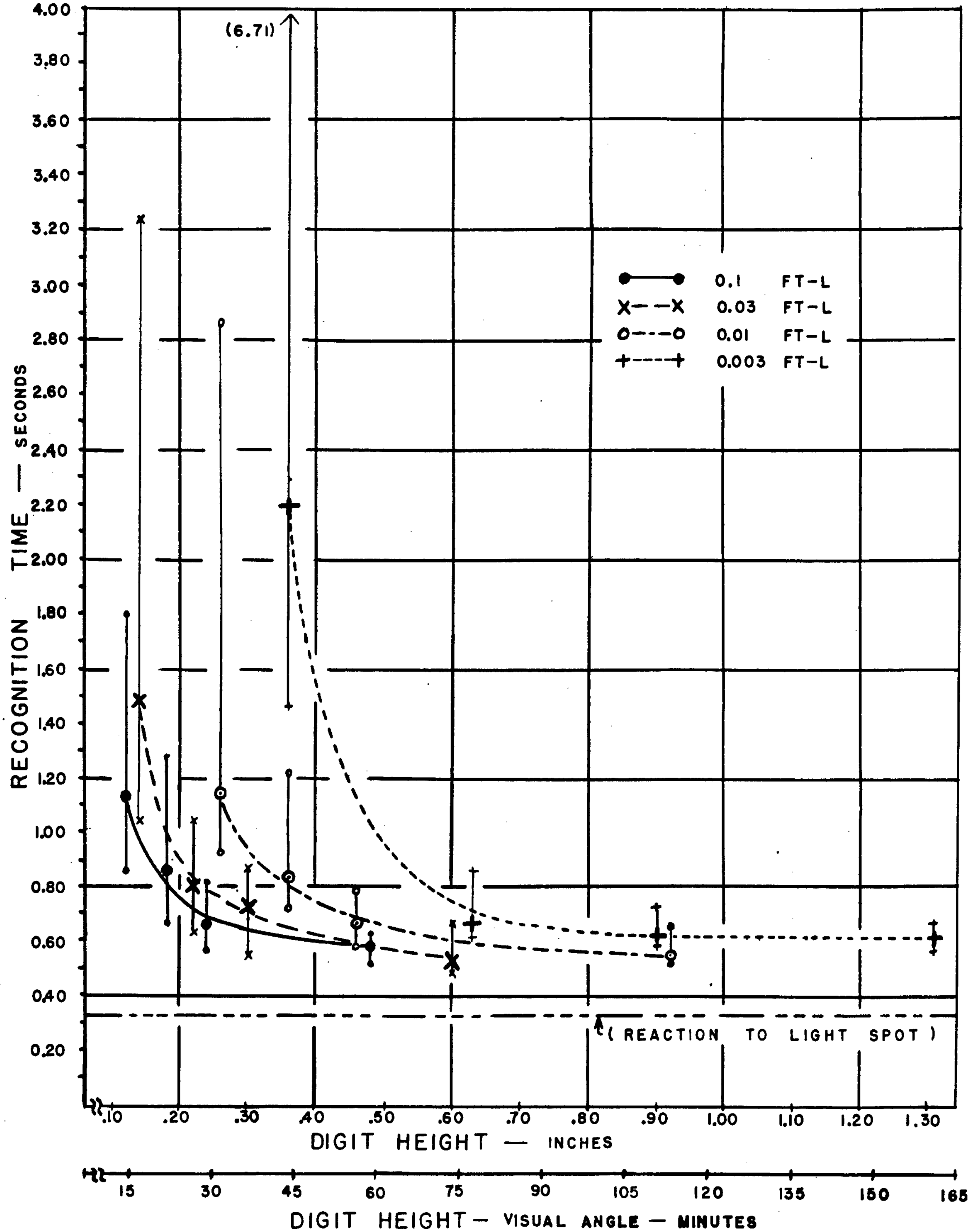

Figure 1. Recognition time for digits presented singly as a function of digit height. Curves show median performance of a group of 16 subjects. Vertical lines through plotted medians show inter-quartile ranges. Reaction time to simple light spot is median for 7 subjects at brightnesses from .003 to .03 ft-L.

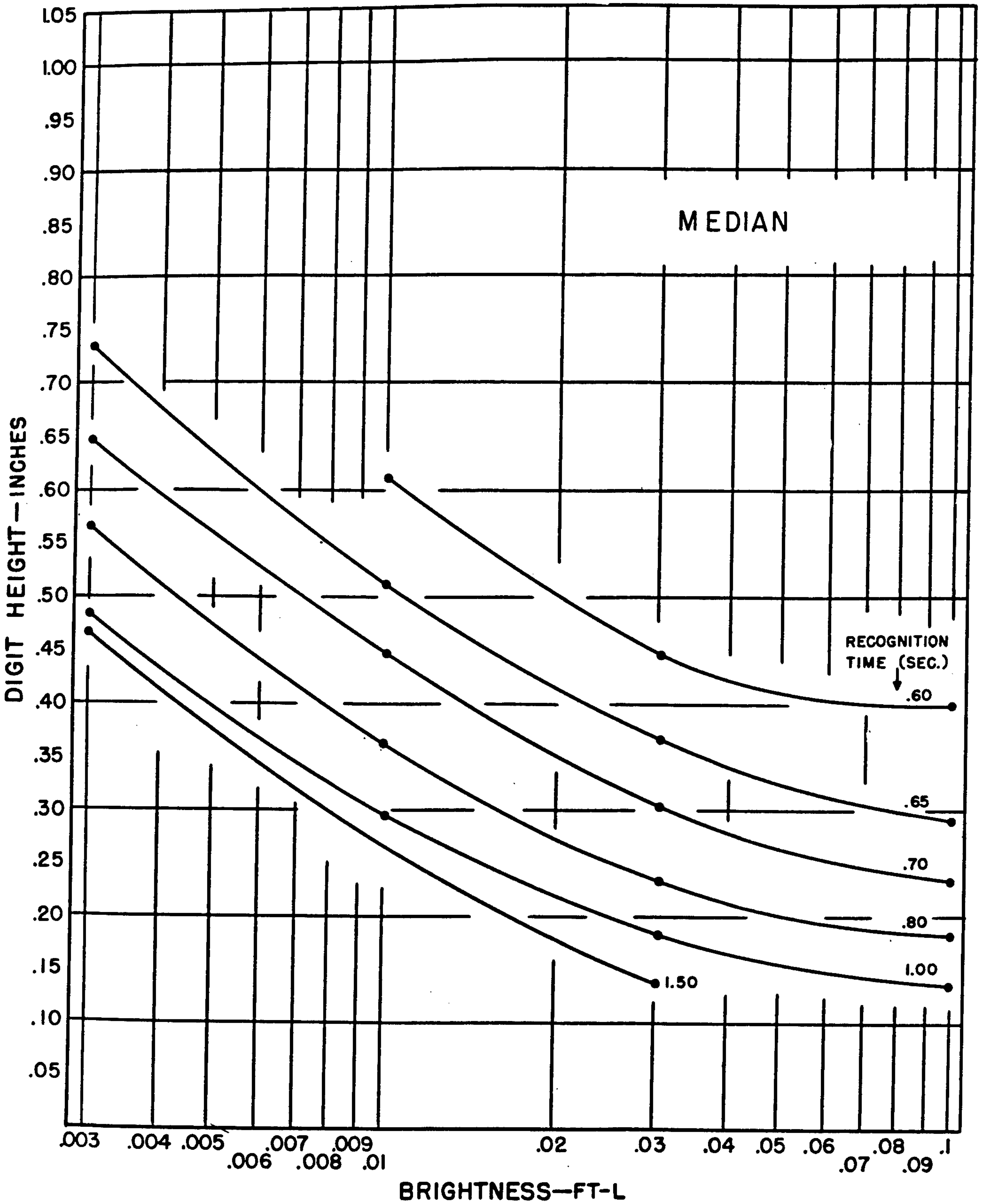

Figure 2. Relation between digit height and brightness, for various recognition times. Median performance of a group of 16 subjects. Derived from the curves of Figure 1.

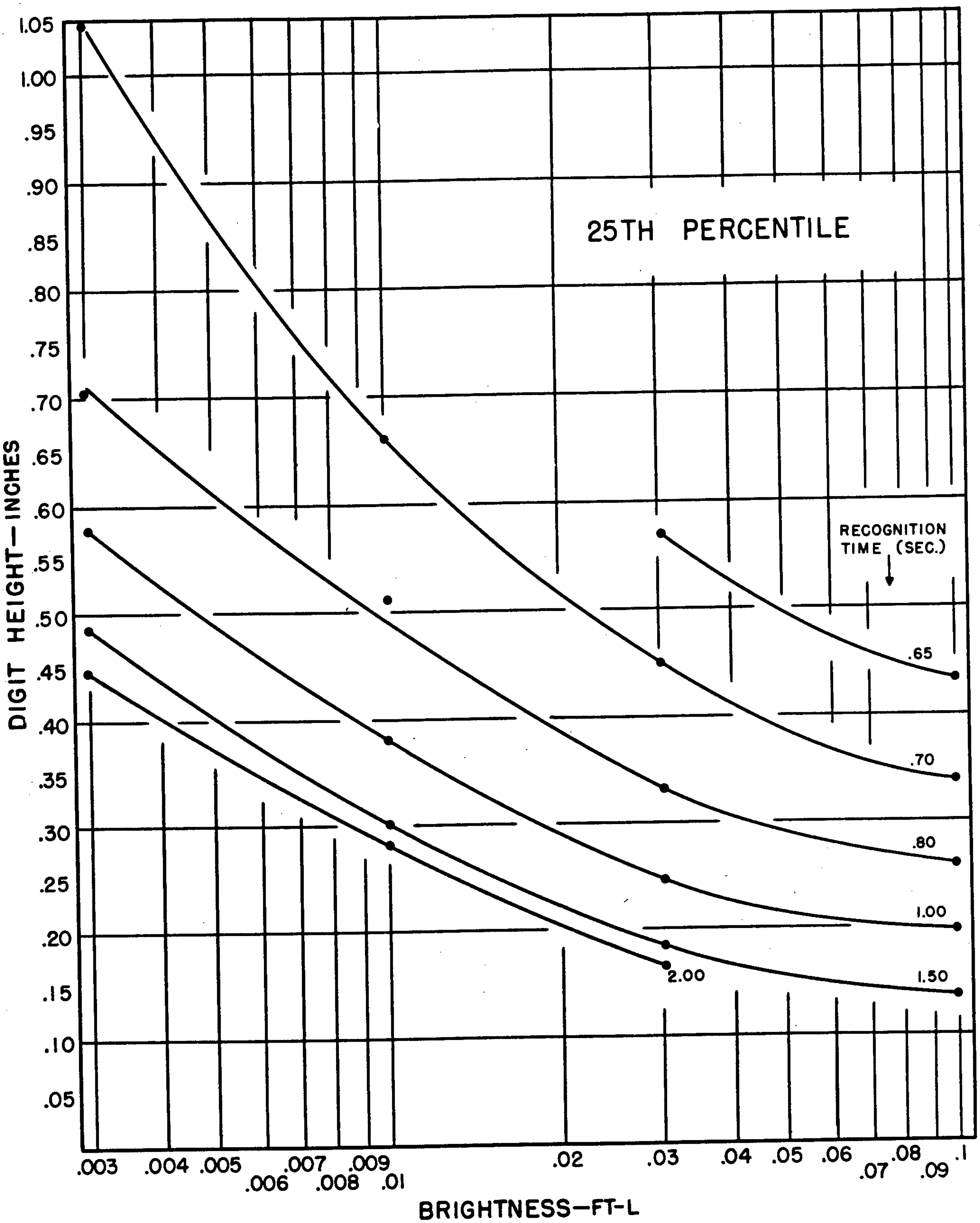

Figure 3. Relation between digit height and brightness, for various recognition times. Performance at the 25th percentile of a group of 16 subjects. Derived from curves drawn through the upper ends of the inter-quartile lines of Figure 1.

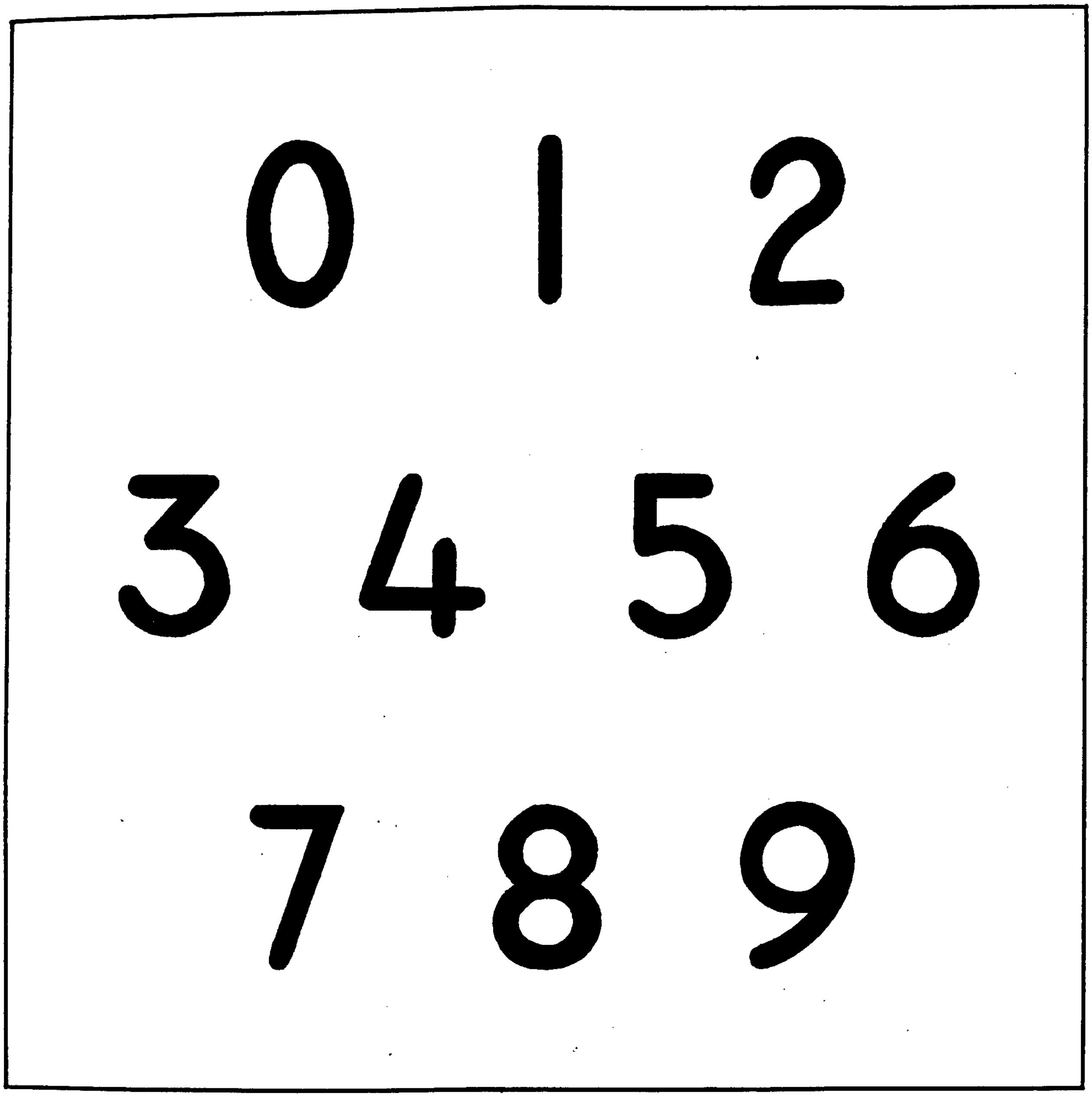

Figure 4. Army-Navy Aeronautical digits used throughout the present study. Height/stroke-width ratio 8/1 (7).

clearly. Skewness is reflected in the greater length of the upper segments of the inter-quartile lines as compared with the lower. Progressive increase in spread and skewness with decreasing digit size is shown by the progressive but asymmetrical lengthening of these lines.

Reverting to Table I B, it will be noted that the means are larger than the medians, particularly for the smaller digit sizes. This is an index of positive skewness, as the means are more influenced by the extreme scores.

It may be helpful to point out that, under "easy" conditions of size and brightness, the score of the worst subject of our sixteen tended to be about twice that of the mean of the group, while under "difficult" conditions it was more often three or four times the mean.

It is unlikely that the general character of these results would be substantially changed by further practice. Lumping all conditions together, our original 16 subjects improved not more than 10% between the mean of trials 1-5 and the mean of trials 116-120.

Figures 2 and 3 are derived from Figure 1, but show digit size as a function of brightness for various recognition times. This puts the data into more convenient form for answering the question, "How large must a digit be for recognition in a given time at a given brightness level?". The curves of Figure 2 are in terms of median performance, and the plotted points are taken directly from the curves of Figure 1. Those of Figure 3 are in terms of performance at the 25th percentile, corresponding to recognition by three-fourths of the subjects, and the points are taken from curves (not shown) drawn through the 25th percentile points of Figure 1. The displacement of the Figure 3 curves toward larger digit sizes is apparent.

It was desired to determine the effect of eliminating some of the poorer subjects. As the design was set up for 16 subjects it seemed advisable to stick to that number, so five subjects among those showing the largest number of ten-second scores were replaced with the next five not previously used in this experiment who qualified on the Lebensohn Test. This nearly eliminated the ten-second scores, a total of ten such scores being divided between the smallest digit sizes for 0.003 and 0.03 ft-L. The means, medians, and quartile points for 16 subjects after the five replacements are shown in Table I C.

A comparison of Tables I B and I C gives a rough idea of the possible gain from screening for low brightness acuity. The accelerated increase in recognition time as digit size decreases shows in both groups and in all indices. At the larger and more recognizable digit sizes, little systematic difference between the groups is apparent. At the smallest digit sizes, medians and 75th percentiles are relatively unaffected, but means and 25th percentiles are substantially lower in Table I C, as would be expected from eliminating the poorer subjects. In other words, the largest gain shows for the more difficult conditions. As our modified group was not screened by any generally reproducible criterion, Table I C is presented mainly for its supplementary interest, and the discussion to follow will be referred primarily to the data of Table I B and Figure 1.

2. Experiment 2: Effect of Digit Grouping on Recognition Time

a. Conditions

In this experiment each digit was presented both singly and between two other digits. Zero and 5 were used as the flanking digits. For each of

the test digits two new slides were prepared, in one of which the test digit was flanked by 0 on the left and 5 on the right (the 0 x 5 pattern), in the other by 5 on the left and 0 on the right (the 5 x 0 pattern). Spacing between digits was 5.4% of digit height, measured between verticals tangent to the outermost points of the digit contours. This is very close spacing but within the range encountered in practice.

The experiment was planned to include a fair sampling of the size and brightness ranges of Experiment 1 but on a smaller scale. Therefore four brightnesses were used, but only one digit size at each, as follows: for 0.1 ft-L, digit height 0.18 in., for 0.03 ft-L, 0.18 in., for 0.01 ft-L, 0.36 in., and for 0.003 ft-L, 0.36 in.

One further special condition should be noted. Single digits were responded to as in Experiment 1, but in the group presentation the subject named all three digits starting at the left. The recorded score is therefore the time to the naming of one of the flanking digits rather than the test digit in the middle position. Characteristically the subjects responded to the set as a unit, naming the three digits in succession without noticeable pauses. Brightness contrast was maximal as in Experiment 1.

Subjects were male college students with 20/25 vision on the Lebensohn Test at 14 inches, and with from one to three periods of previous experience in related experiments. A lower acuity qualification was held to than in Experiment 1 because comparative rather than absolute recognition times were the main concern. Four subjects were used for two periods each.

A single experimental period included either the two higher or the two lower brightnesses. The 20 group slides were matched in the experimental routine by two appearances of the 10 slides for single digits. Four arbitrary digit sequences were prepared for 20 items (10 grouped and 10 single). The first subject in his first period at the first brightness was given the first of these prepared sequences of 20 items, using the 0 x 5 group pattern only, and the sequence was then repeated in reverse order with the same group pattern. The 40 items were then given again using the 5 x 0 group pattern. At the second brightness, the entire procedure was gone through again with a second prepared sequence of items. This made a total of 160 regular trials for the period. In the second period, the two remaining brightnesses were given with the third and fourth of the prepared item sequences. For the remaining subjects the sequences, brightnesses, and group patterns were rearranged to balance out the effect of serial position. The full schedule for a period included four to eight practice or warming-up trials, and a brief rest interval between the two brightnessses.

b. Results

In Table II appear, for grouped and single presentations separately at the several size-brightness combinations, mean and median recognition times on the 10 digits combined, and on nine digits combined the 1 being omitted. Means were computed without the 1 because in our group slides the stroke of the 1 was spaced from adjacent contours by the same distance that separated the vertical tangents in the case of other digits. Crowding of the 1 to this extent would often be avoided in practice, so means based on nine digits may be the more valid for our purposes.

TABLE II

MEAN AND MEDIAN RECOGNITION TIMES FOR
DIGITS PRESENTED SINGLY AND IN GROUPS (4 SUBJECTS)

		RECOGNITION TIME (sec.)					
		BRIGHTNESS .1 ft-L DIGIT HEIGHT .18 in.			BRIGHTNESS .03 ft-L DIGIT HEIGHT .18 in.		
		SINGLE	GROUPED	% DIFF.	SINGLE	GROUPED	% DIFF.
ALL DIGITS	MEAN	.69	.74	7	.80	.85	6
	MEDIAN	.70	.72	3	.78	.80	3
DIGIT 1 OMITTED	MEAN	.70	.73	4	.81	.84	4
	MEDIAN	.71	.70	-1	.78	.80	3
		BRIGHTNESS .01 ft-L DIGIT HEIGHT .36 in.			BRIGHTNESS .003 ft-L DIGIT HEIGHT .36 in.		
		SINGLE	GROUPED	% DIFF.	SINGLE	GROUPED	% DIFF.
ALL DIGITS	MEAN	.83	.92	11	3.77	(5.64)	50
	MEDIAN	.84	.90	7	2.84	(4.60)	62
DIGIT 1 OMITTED	MEAN	.85	.89	5	4.04	5.54	37
	MEDIAN	.86	.88	2	2.99	4.43	48

Underlined figures are based on distributions which include one or more scores arbitrarily limited to 10 seconds.

Figures in parentheses are based on a distribution from which five of the 16 scores for digit 1 are missing.

At a given size-brightness combination, means for 10 digits combined are based on 160 determinations (4 subjects, 4 trials per subject per digit) and means for nine digits on 144.

The original plan called for limiting scores to 10 seconds as in Experiment 1, but when it became apparent that at the lowest brightness the number of scores running over 10 sec. would be substantial, this practice was abandoned and the actual times recorded. At this point, one score for a single digit and six scores for grouped digits at 0.003 ft-L had already been counted as 10 sec.

In five instances out of 16 at 0.003 ft-L, the grouped digit 1 was not reported even after repeated tries. Such a failure to identify could be considered equivalent to a very high time score. But no allowance for these cases was made in the computations, the data of Table II being based on the scores actually recorded. The mean and median for 10 digits in grouped presentation at 0.003 ft-L should therefore be considered minimal values.

It will be seen from the means and medians based on nine digits that, for three of the conditions, grouping increased recognition time by not over 5%. These three conditions were relatively "easy" ones. For 0.36 in. digits at 0.003 ft-L, recognition times were four or five times as long as for the other conditions on the average, and here the grouping made a difference of about 40%. Such an interaction is characteristic for the type of variables dealt with.

The percentage increase produced by grouping tends to be higher when digit 1 is included, as would be expected from the fact that the crowded 1 is relatively difficult.

If we compare each mean with its corresponding median, it is seen that the means are only slightly larger than the medians under easy conditions, but 25 to 30% larger for the 0.36 in. digits at 0.003 ft-L. This reflects the fact that performance of the poorer subjects was impaired relatively more than that of the good subjects by the difficult size-brightness condition, as was found for the larger groups in Experiment 1.

3. Experiment 3: Effect of Digit Grouping on Recognition Time

a. Conditions

In this experiment single and grouped digits were compared as in Experiment 2, but conditions were different in the following respects.

The plan was designed to provide more extensive data at one brightness, 0.03 ft-L. Four digit heights were used, 0.14, 0.18, 0.30, and 0.36 in.

Subjects responded only to the middle digit of a group rather than to the set.

Student subjects were not available because of a break in the school year. Therefore four male members of the staff, ranging in age from 19 to 46

years, were used for two periods each. These subjects had from one to several periods of previous experience in related experiments, and qualified with 20/25 vision on the Lebensohn Test at 14 in.

All four digit sizes were presented in each period. The first subject in his first period was given, for each digit size, one of the 20-item sequences from Experiment 2 with the 0 x 5 group pattern, followed by the same sequence in reverse order with the 5 x 0 pattern. This made 160 regular trials. For the remaining subjects, item sequences were inverted and size sequences rearranged to balance out the effect of serial position. For each subject, the second period was a repetition of the first. The full schedule for a period included from four to eight practice or warming-up trials, and brief rest intervals between the sizes.

b. Results

In Table III are shown, for grouped and single presentations separately at the several digit sizes, mean and median recognition times on the 10 digits combined, and on 9 digits combined, the 1 being omitted as in Experiment 2.

One score for digit 1 was lost because of failure to identify after repeated tries.

The means and medians based on nine digits show increases of recognition time resulting from grouping up to 25%.

The expected tendency for grouping to have more effect under the more difficult conditions does not show, probably because the range of difficulty is small.

The percentage impairment is a little higher on the average with digit 1 included, but there are a number of inversions.

The interaction of difficulty with skewness shows, even though the difficulty range is small. For the two larger image sizes, where the recognition times fall at 0.8 sec. or below, the means tend to be slightly smaller than the medians. For the smaller image sizes, with somewhat longer recognition times, means exceed the medians by increments up to 27%.

The over-all effect of digit grouping was enough larger in Experiment 3 than Experiment 2 to suggest that the different method of reporting may have been a factor. The scores of Experiment 3 measure responses to the middle digit only. They are therefore a more direct index of the recognizability of that digit than those of Experiment 2 in which the three digits were responded to as a group.

4. Experiment 4: Effect of Digit Grouping and Reduced Contrast on Recognition Time

a. Conditions

In most floodlighting systems the background would have somewhat

TABLE III

MEAN AND MEDIAN RECOGNITION TIMES FOR DIGITS
PRESENTED SINGLY AND IN GROUPS. BRIGHTNESS .03 ft-L (4 SUBJECTS)

		RECOGNITION TIME (sec.)					
		DIGIT HEIGHT .14 in.			DIGIT HEIGHT .18 in.		
		SINGLE	GROUPED	% DIFF.	SINGLE	GROUPED	% DIFF.
ALL DIGITS	MEAN	1.56	1.82	17	1.12	1.38	23
	MEDIAN	1.48	1.43	- 3	1.00	1.16	16
DIGIT 1 OMITTED	MEAN	1.59	1.75	10	1.15	1.38	20
	MEDIAN	1.50	1.50	0	1.02	1.14	12
		DIGIT HEIGHT .30 in.			DIGIT HEIGHT .36 in.		
		SINGLE	GROUPED	% DIFF.	SINGLE	GROUPED	% DIFF.
ALL DIGITS	MEAN	.68	(.78)	15	.64	.73	14
	MEDIAN	.66	(.80)	21	.66	.74	12
DIGIT 1 OMITTED	MEAN	.67	.78	16	.64	.72	12
	MEDIAN	.64	.80	25	.66	.73	11

Figures in parentheses are based on a distribution from which one of the 16 scores for digit 1 is, missing.

greater luminosity than our dark screen in Experiments 1 to 3, with corresponding reduced brightness contrast between numerals and ground. This factor, combined with grouping, was tested in Experiment 4.

For this purpose provision was made for flooding the entire 12 by 12 in. screen with light at 0.003 ft-L. The grouped digits were projected against this ground at 0.03 ft-L. The effective brightness for grouped digits was therefore 0.033 ft-L, and the contrast ratio 0.91. Single digits for comparison were projected against the original dark ground, at a brightness of 0.03 ft-L.

Three digit heights were used, 0.22, 0.29, and 0.36 in. In the grouped presentation, subjects responded to the middle digit only.

Six male student subjects, with 20/25 vision on the Lebensohn Test at 14 in., and without previous experience, served for one period each.

Three sequences of 20 items were prepared. The first subject, for each of the three digit sizes, was given 10 items from the first sequence with digits presented singly against the dark ground, followed by 10 items with the grouped digits against a light ground, using the 0 x 5 group pattern; the series of 20 was then repeated in reverse order with the 5 x 0 pattern. This made 120 regular trials for the period. For the remaining subjects, item sequences, blocks of single versus grouped digits, group patterns, and digit sizes were rearranged to balance out the effect of serial position. The full schedule for a period included five to eight practice trials and brief rest intervals between blocks of 10 digits.

b. Results

In Table IV appear, for the two arrangements separately at the three digit sizes, mean and median recognition times on the 10 digits combined, and on nine digits combined, the 1 being omitted as in Experiments 2 and 3.

At a given digit size, means for 10 digits combined are based on 120 determinations (6 subjects, 2 trials per subject per digit), those for nine digits on 108.

The means and medians for nine digits in Table IV show increases of recognition time resulting from grouping and reduced contrast up to 15%. It will be noted that the grouped digits had an advantage in absolute brightness of 10% over the single digits. This difference was tolerated because eliminating it would have complicated the process of changing from one condition to the other in the experimental routine. So far as can be judged from the data of Experiment 1, this could shorten response times in the neighborhood of 1% at the two larger digit sizes, and possibly 4% at the 0.22 in. size. Making due allowance for this factor, the impairment from grouping and reduced contrast together would still not be quite as large as from grouping alone shown in Table III. This result is not as unreasonable as it might appear. Differences between groups of subjects could be a contributing factor. The

TABLE IV

MEAN AND MEDIAN RECOGNITION TIMES FOR DIGITS PRESENTED SINGLY AGAINST A DARK GROUND (SglDk) AND IN GROUPS AGAINST A LIGHTER GROUND (GrpLt). BRIGHTNESS .033 ft-L. (6 SUBJECTS)

		RECOGNITION TIME (sec.)								
		DIGIT HEIGHT .22 in.			DIGIT HEIGHT .29 in.			DIGIT HEIGHT .36 in.		
		SglDk	GrpLt	% DIFF.	SglDk	GrpLt	% DIFF.	SglDk	GrpLt	% DIFF.
ALL DIGITS	MEAN	.78	.88	13	.74	.78	5	.70	.78	11
	MEDIAN	.76	.84	11	.72	.80	11	.67	.78	16
DIGIT 1 OMITTED	MEAN	.79	.86	9	.75	.78	4	.71	.78	10
	MEDIAN	.76	.82	8	.73	.78	7	.68	.78	15

difference between a contrast ratio of 1.0 and 0.91 is not large, and impairments from grouping and contrast together would not necessarily be additive. In this type of situation, moreover, the increased light in the background could aid discrimination by bringing the adaptation level closer to that of the test object, and by providing a better frame of reference for accommodation adjustments.

While the scores can be seen to vary inversely with digit size, the range of difficulty is too small for the interaction of difficulty with either the grouping effect or skewness to show. With digit 1 included, a larger grouping effect is suggested, but the differences are small.

C. Discussion

It will be noted that the mean reaction time to a simple light spot in our situation was 0.32 sec. This is a slow reaction time for male college students, but not unreasonable in view of the low brightness and the experimental context.

The fastest mean recognition times for digits by a group of our subjects were in the neighborhood of 0.6 sec., and medians a little smaller, with the curves not quite leveled off. This agrees well enough with mean digit recognition times reported by Saltzman and Garner (6, p. 236) of 0.46 to 0.50 sec., at the higher brightness level of 2.0 effective foot-candles, with recording through a throat microphone.

Our results can be compared with Craik's (1) in the region where the upper part of his brightness range overlapped the lower part of ours. The agreement is not at all good. At 0.01 ft-L Craik reported reading times of about 1.5 sec. for digits subtending a visual angle of 15'. From our Figure 1 it can be inferred that the median subject would recognize a 15' digit at 0.01 ft-L only after several seconds, and a subject at the 75th percentile of our group would not do much better. As an informal check, an experienced subject observed digits of that size and brightness in our situation in both the American Aeronautical design and in Craik's design, which has a thicker stroke. Both types of digits could be identified better than chance, but in most cases the subject could be "reasonably sure" as required by our formal instructions only after some seconds, if at all.

A further check on these discrepant results is available from a quite different series of experiments carried out in this Laboratory and reported elsewhere (2). In this series the subjects had the task of reading numerals in various sizes printed black on white at a reading distance of 14 in. The 6-point type in this series subtended a visual angle between 15' and 16'. The type was of a different style from the Aeronautical design, but the visual field was favorable for good accommodation. Subjects had the option of not completing a 50-item trial after attempting a few items if the material seemed unreadable. Of 12 subjects presented with the 6-point type at 0.01 ft-L, five gave up, six finished the trial with error scores slightly better than chance, and one finished with a score substantially better than chance.

It may be that Craik's two subjects had unusually good vision, or it may be that his task was different from ours. The report of Craik's work available to us is a Flying Personnel Research Committee summary which does not give much detail of experimental procedure. In closely related studies Craik used a dial reading task. If this was the test also for numeral legibility, position cues might account for the higher level of performance. Our study was directed at the legibility of numerals per se, without secondary cues or superimposed tasks.

Craik's results can be compared with ours on a second point. Craik found that, for constant legibility, the square of the digit height varied approximately inversely with the brightness. For the relatively small brightness region from 0.003 to 0.01 ft-L common to the two experiments, our data are not inconsistent with this finding. But as brightness increases further a point is reached at which digit area for constant recognition time no longer decreases and the relation breaks down. The longer the recognition time the lower this critical brightness value.

Interpretation of our own results will be based mainly on the data of Table I B and Figure 1. It is therefore well to have in mind possible limitations of these data. If means instead of medians had been plotted in Figure 1, the upper branches of the curves would extend much higher and the drop would be steeper, but the relatively level regions would start only a little farther to the right. The curve for 0.003 ft-L would level off somewhat above the level for medians. Most of the inferences to be drawn about practical applications would be affected very little.

If medians and quartiles from our modified group of Table I C were plotted instead of those from the original group, the medians and the bottom ends of the inter-quartile lines would fall a little lower on the average, the difference being generally less than 10%. The upper segments of the inter-quartile lines would be shortened down to make the lines almost symmetrical around the medians, resulting in considerable change at the more difficult size-brightness conditions, but relatively little change in the level regions of the curves where the inter-quartile ranges are small. The picture, then, would be about the same at the easy size-brightness conditions, and about the same throughout for subjects at the median of the group or above, but quite different at the more difficult conditions for those at the 25th percentile.

Sixteen subjects are not a large sample, but in addition to the five replacement subjects we have 14 new subjects in Experiments 2 to 4, for an over-all total of 35. If we make such comparisons as are possible among the experiments on the basis of identical conditions, the performance of the smaller groups is found to vary around that of the original group of 16, in spite of the fact that they were selected by a lower criterion on the Lebensohn acuity test. Figure 1, therefore, can be taken to represent fairly well the central tendency of all our data.

Considering the curves of Figure 1 it will be noted, not only that they approach final levels as digit height increases, but the final levels for all

four brightnesses fall between 0.50 and 0.65 sec. In other words, once recognition time has been reduced to a certain point, further increases in either size or brightness will have very little effect. If we should desire to assign an arbitrary value to this critical point for the median subject, a reasonable choice would be 0.70 sec.

To permit recognition by the median subject within 0.70 sec., a digit at 0.1 ft-L would have to be no less than 0.23 in. high, a digit at 0.03 ft-L would have to be 0.30 in. high, one at 0.01 ft-L, 0.44 in. high, and one at 0.003 ft-L, 0.64 in. high.

A comparable cut-off point for the 25th percentile, permitting recognition by three-fourths of the subjects within about the same size-brightness limits, would be 0.85 sec. For mean scores, the corresponding cut-off value would be between that for the medians and the 25th percentiles.

Above the cut-off point, changes in either size or brightness have relatively large effects on performance. As previously indicated, the same general relation holds for secondary variables as for size and brightness. Such factors as differences between subjects, digit grouping, and a moderate reduction in brightness contrast modify the lower branches of the curves very little. Our data on the effect of individual differences and digit grouping extend to the more difficult size-brightness combinations, and here the effects are large.

To minimize variability of recognition time in operational situations, it would be desirable to keep the size-brightness combinations within the regions covered by the lower branches of the curves in Figure 1. But other considerations make this an impractical goal. For example, the size and design of dial faces sometimes makes it necessary to limit digit height to 3/16 in.; but to bring digits of this size within the desired region the brightness would have to be 0.1 ft-L or above; that of 1/8 in. digits would have to be even greater. Such values of white light would result in a substantial loss of dark adaptation. Even with red light they would be too high for adequate adaptation in some situations. Craik (1) suggests an upper limit for red lighting of 0.05 ft-L. If brightness is held below these values, it is necessary to accept somewhat longer, and more variable, digit recognition times.

For a proper interpretation of red light values in this connection it is necessary to note that red light has been reported by the Admiralty Research Laboratory (3) to be superior to white light for acuity and reading functions at brightnesses below about 0.1 ft-L. It is stated that in the neighborhood of 0.06 ft-L, for equal speed of reading unrelated words, about 60% more white than red light is required. On this basis Craik's upper limit of 0.05 ft-L for red would be equivalent to about 0.08 ft-L for white.

For a digit at a brightness of 0.08 ft-L (white light) to be recognized in 0.7 sec. by half the subjects, or in 0.85 sec. by three-fourths of the subjects, it would have to be about 1/4 in. high. If it is assumed that space limitations make 1/4 in. numerals impractical, it follows that no clear optimum is indicated. Compromise adjustments will depend, not only on data such as these, but on various related considerations as well. A few examples can be given. Loucks (4) found some evidence of greater confusion with larger

dial numbers because of the difficulty of relating them to the appropriate scale marks. The marks in question, however, may have been insufficiently differentiated on the dials he used. Legibility of numerals per se may be less critical on dial scales, where the spatial arrangement becomes familiar, than on odometers where the numerals stand alone. If types of operational situation can be distinguished requiring different habitual levels of dark adaptation, the amount of red light provided could be varied accordingly. If certain numerals which had to be read occasionally could not be made large enough for legibility under standard red floodlighting, a supplementary red spotlight might be used for a few seconds without serious loss of dark adaptation.

D. Conclusions

Average recognition time for dial type digits 0.48 in. high presented singly, at a brightness of 0.1 ft-L with maximum contrast, is approximately 0.6 sec.

Decreases in size or brightness from this level produce at first a gradual and then a more rapid increase in recognition time.

If it should be desired to select a cut-off point in terms of recognition time, above which the time increases rapidly as conditions become less favorable, the data here reported suggest 0.7 sec. for the median of a group of subjects. To permit recognition within this interval, a digit at 0.1 ft-L would have to be 0.23 in. high, one at 0.03 ft-L would have to be 0.30 in. high, one at 0.01 ft-L, 0.44 in. high, and one at 0.003 ft-L, 0.64 in. high.

A comparable cut-off point for the 25th percentile, permitting recognition by three-fourths of the group within about the same size-brightness limits, would be 0.85 sec.

In the region where the effect of size and brightness is relatively small, the effect of secondary factors such as differences between subjects, grouping of digits, and moderate reduction of brightness contrast, is also relatively small; where a reduction in size or brightness is sufficient to produce a large increase in recognition time, the effect of the secondary variables is also large.

Unfavorable conditions impair the performance of the poorer subjects relatively more than of the better subjects.

Size-brightness combinations below the cut-off point involve either digits that are too large for available dial space, or brightnesses too high for the preservation of dark adaptation; in operational situations, compromises are therefore necessary.

BIBLIOGRAPHICAL REFERENCES

1. Craik, K. J. W. Instrument lighting for night use. FPRC 342. Great Britain Air Ministry. July, 1941.

2. Crook, M. N., Harker, G. S., Hoffman, A. C., and Kennedy, J. L. Effect of amplitude of apparent vibration, brightness, and type size on numeral reading. USAF Technical Report No. 6246. United States Air Force, Air Materiel Command, September, 1950.

3. Great Britain Admiralty Research Laboratory. Ease of reading and visual acuity in red and white light. ARL/N3/0.360. August, 1942.

4. Loucks, R. B. Legibility of aircraft instrument dials: A further investigation of the relative legibility of tachometer dials. Project No. 265, Report No. 2. United States Air Force, School of Aviation Medicine, October, 1944.

5. Roush, R. G., and Hamburger, F., Jr. An electronic chronograph for measurement of voice reaction-time. Amer. J. Psychol., 1947, 60, 624-628.

6. Saltzman, I. J., and Garner, W. R. Reaction time as a measure of span of attention. J. Psychol., 1948, 25, 227-241.

7. United States Army-Navy. Numerals and letters - standard form of aircraft instrument dial. Army Navy aeronautical design standard, AND10400. October, 1944.